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AIR POLLUTION SURVEY. REPORT 2. METEOROLOGY AND AIR POLLUTION IN THE DELAWARE VALLEY

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Regional Conference of Elected Officials
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LABORATORY OF CLIMATOLOGY

METEOROLOGY AND AIR POLLUTION IN THE DELAWARE VALLEY

SUMMARY AND CONCLUSIONS

by

John R. Mather

The project was supported in part by Public Health Service Grant No. 66 A-5604Z, made by the Division of Air Pollution under P.L. 88-206, the Clean Air Act.

Period of Study
July 28, 1966 - October 31, 1967

This Summary and Conclusions report, abstracted from the Final Report on Meteorology and Air Pollution in the Delaware Valley, prepared under contract from the Regional Conference of Elected Officials, attempts to make readily available the most significant results of the study. More complete results, data, analyses, and descriptions of techniques used will be found in the Final Report itself.

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November 1, 1967

RCEO
AIR POLLUTION
SURVEY REPORT

GENERAL PREFACE

The atmosphere is, by all odds, man's most vital natural resource. Until quite recently, we lived comfortably with the ambivalent views that (1) the atmosphere can be used freely for the disposal of the airborne waste products of an industrialized society, and (2) that people are, at all times, entitled to air in a form which will enable them to live cleanly, comfortably, and in good health.

With the recognition that we now dump more than 133 million tons of aerial garbage into the U. S. atmosphere each year, and recent grim reminders of possible mass death afforded us by stagnant, heavily polluted atmosphere over our metropolitan areas, that comfort no longer exists. As a society, it seems clear that we are irrevocably committed to the development of new public policy, new organizational and institutional forms, and new technology which will insure a safe, healthy atmosphere.

As unique evidence of that commitment, the Regional Conference of Elected Officials, Inc., (RCEO) has sponsored this study of the air pollution problem in the vast 11-county, tri-state region centered on Philadelphia. Part of the unique commitment to action is reflected in the financing arrangement for the study which involved a grant from the United States Public Health Service and the individual contributions of local units of government throughout the region. Further, this study effort provides new evidence that autonomous local units of government can join together in a cooperative venture to solve a common problem.

The Region, for purposes of this study, encompasses the three metropolitan areas of Philadelphia-Camden, Trenton, and Wilmington, located in Pennsylvania, New Jersey and Delaware respectively. The area extends generally along the Delaware River from Mercer County, New Jersey, in the north to New Castle County, Delaware, in the south. This area, about 4,545 square miles in extent and with a present population of over 5 million, forms an approximate rectangle 80 by 57 miles in size and oriented with the major axis NE-SW.

Exceeded only by the area centering on New York City, this Philadelphia tri-state region has the most complex governmental structure of any urban area in the United States, consisting of 11 counties and 377 municipalities in parts of three states.

The pattern of urban development and industrial concentrations makes it reasonable to consider the Region a discrete area for investigation of air pollution control problems. The urbanized portion of the Region is, in the main, concentrated along both sides of the Delaware River and rarely extends more than a dozen miles inland. A high percentage of the Region's 9,000 highly diversified manufacturing establishments are located within this band along the River.

The end objective of the study is to define the requirements for the development of an air resource management and control system appropriate to the solution of the →P 2

problem in the 11-county tri-state Region, and, specifically, to determine the governmental machinery and arrangements through which such a system can operate effectively. The design of a viable management and control system for air pollution must be based on: (1) knowledge of the technical characteristics and dimensions of the problem in terms of the real and potential impact; (2) careful exploration and definition of major approaches in developing the technical methods and procedures to resolve the problem; and (3) construction of the optimal governmental framework, legal base, and administrative procedures through which the functional resolution of the problem can be implemented.

In keeping with this basic approach, the study was organized into three areas: 1) Emissions Survey, 2) Meteorological Analysis, and 3) Governmental Aspects. A separate component technical Report, each with a separate summary, has been prepared under each of these titles. The Emissions Survey was performed by Environmental Engineering and Science, Drexel Institute of Technology; The Meteorological Analysis was performed by C. W. Thornthwaite Associates Laboratory of Climatology; and the Governmental Aspects were analyzed by the Fels Institute of Local and State Government, University of Pennsylvania. A Report containing a review of study findings and implementation of study proposals accepted by RCEO will be prepared by the RCEO staff under Executive Director Chester A. Kunz, Rear Admiral, U. S. Navy, Retired.

The study operated under the general direction of the RCEO Air Pollution Committee with the Hon. John E. Babiarz, Mayor of Wilmington, Chairman.

The study benefited from the interest and efforts of the Technical Advisory Committee which was formed to provide general guidance and counsel at specific intervals. Committee members, representing the Air Pollution control agencies of the three states and the City of Philadelphia, were: Victor Sussman and Frank Willard, Jr., for Pennsylvania; William Munroe and Martin Sanvito, for New Jersey; John C. Bryson and James T. Wilburn, for Delaware; Arthur Wallach and Larry Himmelstein, for Philadelphia.

It should be noted that the findings, conclusions, and recommendations of the technical reports are the sole responsibility of the respective contractors, and the acceptance of these findings and conclusions along with recommendations for implementation will be the responsibility of RCEO.

The study is indebted to the many public and private officials of governmental agencies, business organizations, and civic groups which have cooperated through their sustained interest and active assistance. The efforts of all these participants can best be rewarded by the adoption of a program to insure a safe, healthy atmosphere for all citizens of the Region.

Regional Conference of Elected Officials

June, 1968

Introduction

Once waste products have been discharged to the atmosphere, their subsequent movement, concentration, or dispersal, and their final removal from the atmosphere becomes, in large measure, a meteorological problem. Certain atmospheric influences might be chemical, or physical, or possibly even biological, but meteorological influences are still primary as far as the history of the waste products is concerned. Even though waste products may be introduced into the air at an almost constant rate, day to day changes in meteorological conditions will, at times, render them harmless by dispersal and dilution and at other times concentrate them to a choking, odorous, possibly lethal density. Meteorological conditions determine whether the materials released here will affect conditions here or in some other place miles away.

Two meteorological elements are of primary concern in air pollution problems. They are the wind (wind speed and direction and their change with height) and the temperature structure through the lowest air layers.

The wind direction is important in determining where air pollutants come from and where they will be going. Wind speed tells us something of the rate of movement as well as giving us an indication of the turbulent mixing power of the atmosphere. The rate of change of wind speed and direction with height, the wind shear, provides a measure of the ability of the air to disperse or dilute contaminants. The temperature distribution with height through the lowest air layers is directly related to the stability of the atmosphere and hence its ability to disperse pollutants. When temperature decreases with height, the air near the surface has a tendency to rise and mix with air above it and pollutants will be carried upward and dispersed. When temperature increases with height, a situation known as a temperature inversion, air near the ground is colder and heavier than the air above and vertical mixing of the air and its contaminant load is greatly limited.

The relationship between stability and concentrations of contaminants is direct; that is, the higher the degree of atmospheric stability the greater the concentration at the ground. With a rapid temperature decrease with height in the lowest layers of the atmosphere, diffusion is rapid and ground concentrations of pollutants are low. With large temperature inversions, horizontal eddy diffusion is decreased and vertical eddy diffusion is practically eliminated, leading to concentrations of contaminants near the ground.

Radiative cooling during the night may produce a temperature inversion in the lowest few hundred feet of the atmosphere, restricting vertical motion and causing high concentrations of contaminants beneath the inversion. During the first few hours after sunrise, insolation may break up this inversion with the layer of unstable air growing from the ground upwards. In this layer, turbulent diffusion occurs entirely downward, bringing possibly high concentrations of contaminants to ground level, even at relatively large distances from the stack itself. This process is known

as "fumigation". These concentrations may persist from 15 to 30 minutes, after which the inversion is entirely broken up and turbulence throughout the layer causes rapid dilution.

While ground concentrations are practically zero at the onset of an inversion, they may become extremely high if a persistent inversion results in the inversion layer becoming choked with pollutants. The existence of a simple nocturnal inversion may result in temporarily high concentrations of contaminants at the ground surface the following morning during the period of inversion break up.

Any study of meteorological conditions as related to air quality must, therefore, be concerned with wind and temperature data, not only as they exist at the surface but also as they vary both horizontally and vertically with time. The Delaware Valley area of concern in the present study (11-county RCEO area) is relatively well endowed with surface weather observing stations. More than 20 stations can be found from which values of hourly or three-hourly wind speeds and directions at or near the earth's surface can be obtained. However observations of wind at some level above the surface are taken regularly at only two known places (at 250 ft on a stack near Delaware City, Delaware, and at several levels to 890 ft on the WFIL-KYW tower in Philadelphia) and profiles of air temperature are taken at only one place (various levels to 890 ft on the WFIL-KYW tower). No current observations above 890 ft are known in the whole area in spite of the importance of this information in air pollution studies and the existing air pollution problem in the Delaware Valley area. Information on wind and temperature structure above 890 feet must come either from observations taken more than a decade ago by a radiosonde (balloon-borne meteorological sensor that reports temperature, humidity, and pressure by radio as the balloon rises through the atmosphere) station in Springfield, Delaware County or currently, by radiosonde stations in Pittsburgh, Washington, or New York. Such distant observations are of only limited usefulness in any analysis in the 11-county Delaware Valley area.

Topography and Air Flow in the Delaware Valley

One question that always arises when air pollution is discussed is the question of airsheds or air basins. Laymen have the idea that in certain geographic basins or regions, the lower atmosphere can be treated as an entity, separate from the air in the next adjacent basin just as precipitation and water runoff can be considered by watersheds in hydrology. In mountainous terrain, such as in the Rockies or along certain portions of the west coast, the concept has some validity but in a flat open area such as the eastern seaboard of the United States, the analogy to watersheds becomes much more tenuous. It is clear from a study of the pattern of air flow over the Delaware Valley area in relation to the topographic features of the region that the concept of an airshed has no real significance.

The entire eastern seaboard area of the country covering the region from the Appalachian-Allegheny mountain ridges eastward to the coast is relatively flat or gently rolling. It is clear that at least the area

from Virginia north to Massachusetts and from the coast westward to the Appalachian-Allegheny region has to be considered as a fairly continuous, uniform region without barriers or divides as far as the flow of air is concerned. Pollutants introduced into the air at one place can move without topographic hindrances to any other palce in this large geographic area provided wind conditions are correct.

The uniformity of the wind flow over the whole study area is clearly illustrated by means of monthly maps of prevailing wind directions at all available stations (figure 1). While there is a slight shift in general wind flow from northwest in winter to southwest in summer, the general agreement in wind direction arrows over the whole area emphasizes the homogeneity of the region and the basence of any large basins or areas of restricted air flow.

It must be recognized, of course, that there still will exist within this broad geographic region, small areas where intensification of pollution conditions will occur as a result of local topographic features. These areas are of such small extent (restricted portions of river valleys, isolated basins in rolling terrain) that they can hardly be called airsheds on their own and they produce only localized eddies or backwaters in the general air flow over the broader basin. There is no easy way to identify or study these restricted areas without detailed, time consuming and expensive topoclimatic surveys but they are of only limited importance in the whole problem of meteorology and air pollution over the Delaware Valley area.

It is clear from a study of the topography and air flow in the area that no portion of the 11-county study area is any more or less prone to lowered air quality. Certain regions do have more incidence of pollution but this is because of the distribution of pollution sources rather than because of the existence of circulation or topographic conditions.

Analysis of Wind in the Delaware Valley

Wind speed and direction are usually illustrated by means of wind roses, circular diagrams which show by means of arrows the direction of the wind and the frequency of different wind speeds. The bars or arrows point toward the center and indicate that the wind is blowing from the direction indicated toward the center.

Annual wind roses for six selected stations in the Delaware Valley area are given in figure 2. Two of these stations, Allentown and Wilmington, are maintained by the U.S. Weather Bureau while the other four stations are maintained by local industries. The Allentown and Wilmington wind roses show a pattern which might be anticipated for this area located as it is in the mid-latitude belt of generally westerly flow. Prevailing wind directions at Allentown and Wilmington are westerly in general, being possibly more northwesterly at Wilmington and southwesterly at Allentown. All of the westerly directions show relatively high frequencies.

The two New Jersey stations, Burlington and Mercer, have somewhat the same pattern of distribution although the variation from one direction to another is more marked. At Burlington there is a high frequency of winds from south-southwest, from west, and from north with lower values in the southwesterly and northwesterly sectors. At Mercer, on the other hand, there is a very high frequency of winds from the west with practically no winds from the northwest direction. The value of less than 2 percent frequency of winds from northwest seems suspect in view of the very high values from the north-northwest and westerly directions.

Even more marked variations are found when the Bristol, and Marcus Hook wind roses are considered. Bristol, located north of Philadelphia, has a very high frequency of winds from the northwest and north-northwest with practically no winds from the west or the east during the year. At Marcus Hook, there is a much larger number of southwesterly winds. The differences among Burlington, Mercer, Bristol, and Marcus Hook must lead one to suspect the accuracy of some of the results.

The taking of meteorological observations at industrial sites is usually only the part-time responsibility of a man not trained in meteorology. Therefore in most industries the instruments are a) installed without a great deal of thought about proper exposure of the sensors to insure that they are uninfluenced by nearby buildings; b) operated for long periods without servicing or recalibration so that errors may creep into the records; and c) producing records that are often not evaluated or used except under unusual circumstances. Such records must be evaluated with a great deal of care in order to eliminate those containing errors due to exposure or operation of the sensors themselves. The real solution to this problem, of course, is to encourage industries to obtain competent aid in the installation, calibration, and servicing of meteorological sensors, and in the recording and analysis of the data obtained.

General Circulation Patterns and Pollution

A study of the general weather maps during periods of significantly high and low pollution has revealed that the majority of the low pollution periods are associated with significant precipitation in the area, fairly strong northwest winds and a polar continental air mass moving over the area from Canada. Most often the low pollution episode is initiated by the passage of a cold front with a deep low pressure center north of Philadelphia. The high pressure area that pushes in behind the front brings cold, clear, northwest winds. Low pollution levels remain as long as the northwesterly flow continues.

High pollution levels are not as clearly related to particular circulation patterns. In general, the Philadelphia area seems to be influenced by a weak high pressure area, with light winds and little or no precipitation. The high pressure area remains stagnant over the area for several days or moves slowly to the southeast. The area is then on the western side of the high which results in generally southwesterly winds.

PREVAILING WIND DIRECTION (ALL VELOCITIES), DELAWARE VALLEY AREA

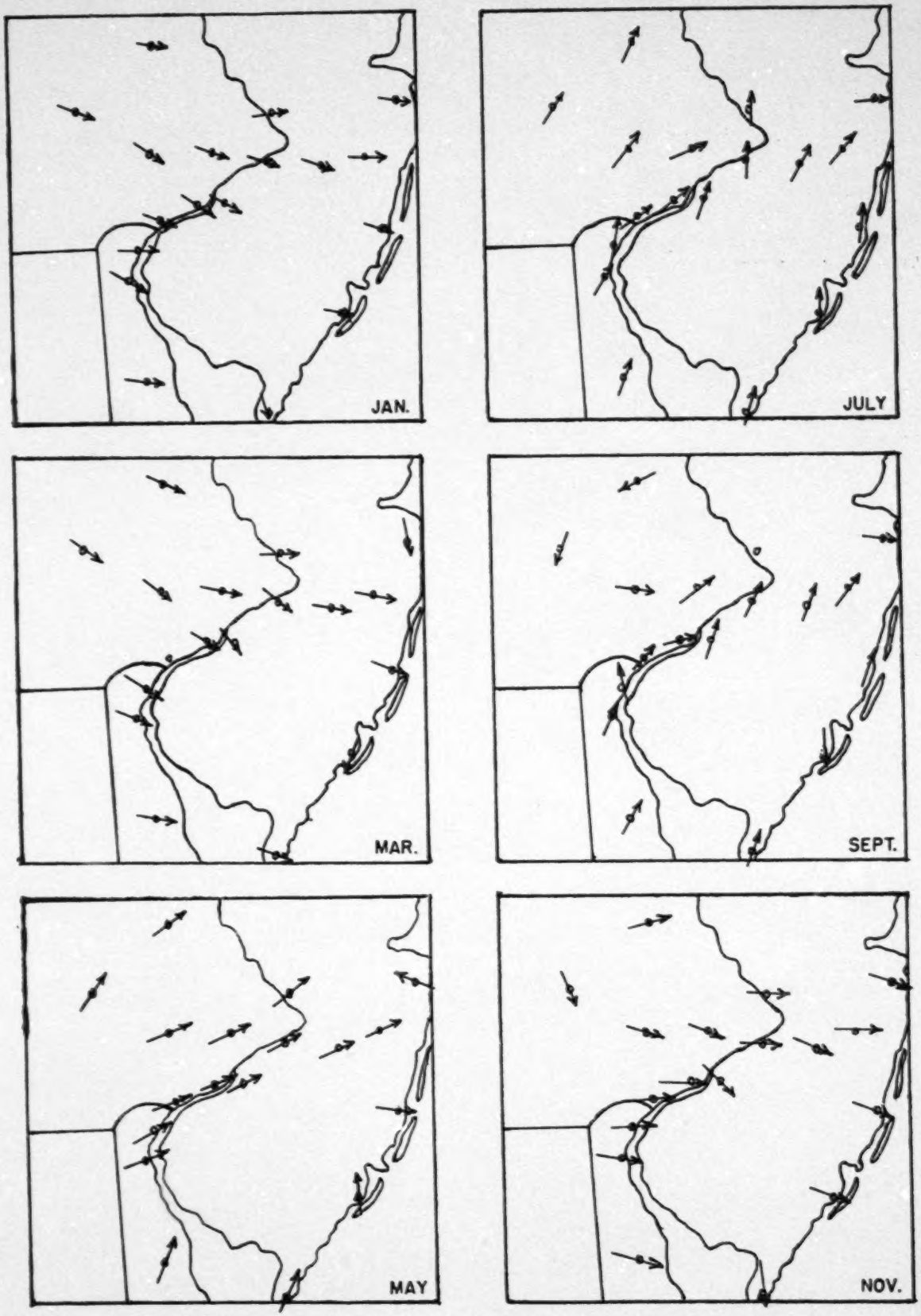

Figure 1

ANNUAL WIND ROSES AT SELECTED DELAWARE VALLEY STATIONS - 1965

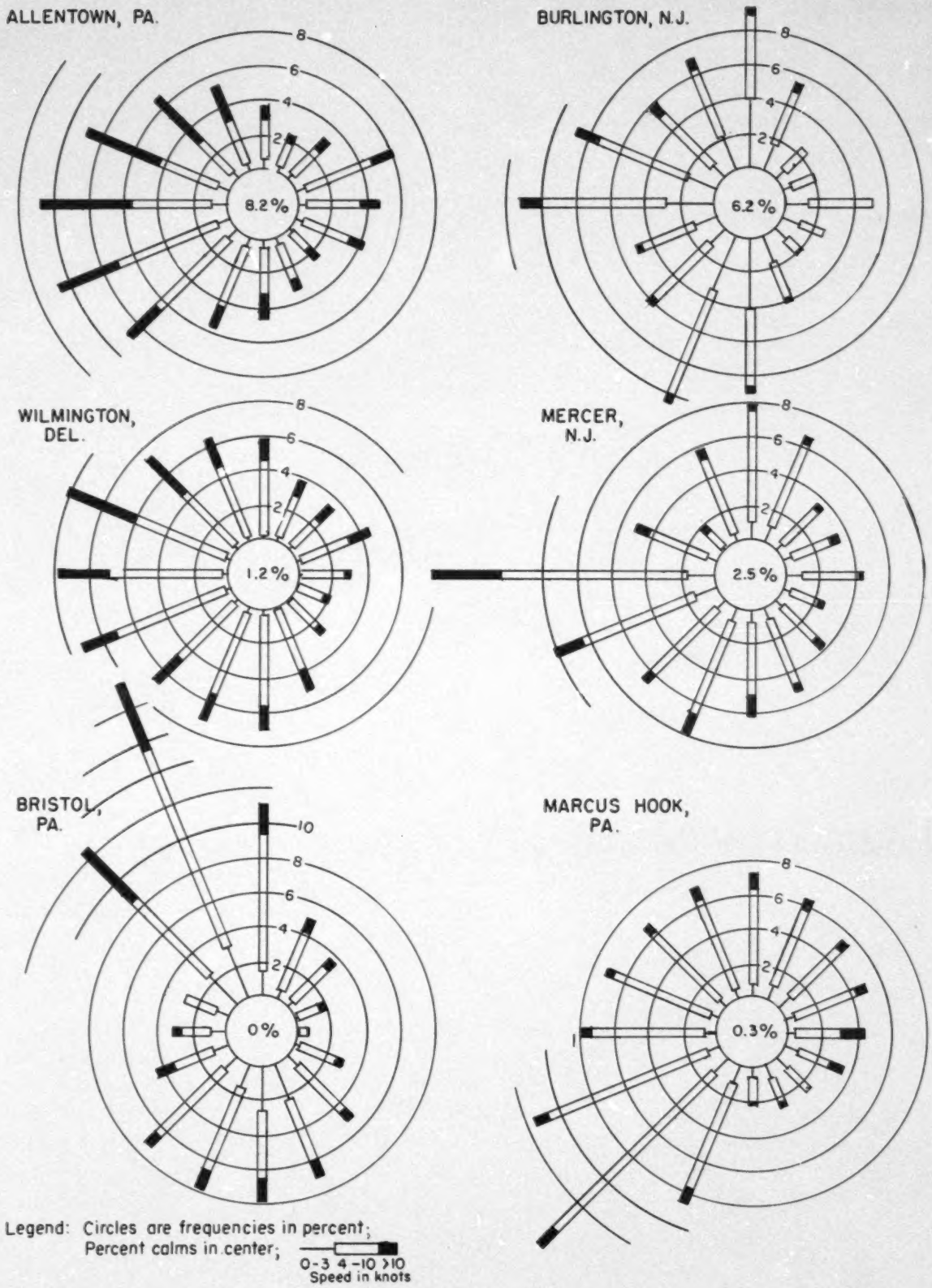

Figure 2

The relation between the general circulation or the synoptic weather conditions and air quality does not appear close enough to allow predictions to be made about air quality a day or so in advance. While very high levels of air pollution will not occur with strong northwesterly winds accompanying a polar continental outbreak, there are a number of other meteorological situations which will also result in lowered pollution levels. The weather maps also reveal many different synoptic situations during which increased air pollution is found over the study area. While high pollution is associated with light winds, slow moving pressure systems, and oftentimes high pressure, there are enough times when similar situations occur without high pollution to make it extremely difficult to forecast periods of high atmospheric pollution from the synoptic weather map alone.

Atmospheric Stability in the Delaware Valley

Investigations of the vertical depth through which dispersion of pollutants takes place have followed two lines: a) studies of frequency, duration, thickness, and stability of temperature inversions in the atmosphere; and b) studies of the frequency, depth, and persistence of mixing depths in the atmosphere.

Based on radiosonde observations taken just outside Philadelphia during 1954-56, the monthly number of marked temperature inversions (4°F or greater increase in 600 feet) ranges from 0 in January to 25 in July. The five summer months of May-September experience 77 percent of all such inversions. There is also a tendency for inversions to last longer in the middle of the summer and in the fall than at other times. All of the marked inversions which persisted for six days or more fell within the June-September period. During the period of record there were no marked inversions lasting over three days in any of the winter months.

The concept of the mixing depth has been developed in an attempt to obtain another indication of the potential mixing of the atmosphere due to afternoon heating from the surface. The maximum mixing depth (MMD) has been defined as the depth of atmosphere through which vigorous mixing could occur as a result of heating of the air layer by conduction-convection during the afternoon. The lower the mixing depth the greater the possibility of air pollution, other things being equal.

Very few examples of mixing depths less than 500 meters lasting at least one day have been found using records from New York, Pittsburgh, and Washington (closest available stations). Those cases that did occur were found primarily in January and December. Very low mixing depths persisting for some time is a wintertime phenomena. Mixing depths less than 1000 or 2000 meters and existing for several days are found to occur more frequently in fall or late summer.

The mean mixing depth, by itself, or even combined with relevant wind data is not an overall index of potential for air pollution. It can still be utilized, with value, as a forecasting tool because of the need to have low mean mixing depths and low wind speeds along with other meteorological and non-meteorological conditions before serious pollution conditions can develop.

Air Quality in the Delaware Valley

The general pattern of air quality in the Delaware Valley is one of serious but not extreme conditions in any of the pollutants measured. The potential for very serious pollution exists and it is only because of the relatively favorable meteorological conditions that more serious pollution episodes do not develop.

Average values of suspended particulate concentration based on 20 to 30 random 24-hour samples during the year have been obtained from all available observing stations and plotted on a map of the area. Lines of constant suspended particulate concentrations have been drawn on the map at 20 $\mu g/m^3$ intervals. There may be some question of the validity of a map of suspended particulates based on so few spot samples which may not necessarily be representative of a significant area around the observing site. The resulting pattern, however, seems entirely consistent and reasonable.

Figure 3 shows a possible annual distribution of average air quality in the 11-county area based on values of suspended particulates in micrograms/cubic meter for 1965. The center of pollution is the city of Philadelphia with a fairly narrow band of high values of suspended particulates running northeast-southwest along the highly industrialized river valley from just south of Wilmington to just north of Trenton. This band does not extend to any great degree in a northwest-southeast direction as is shown by the much lower values of suspended particulates at Glassboro and Pemberton to the southeast and Eagleville and Warminster to the northwest. A secondary high area of suspended particulates is found in the vicinity of Sanatoga located just east of Pottstown in western Montgomery county. Local industrial and population sources in this area evidently result in a higher value than is found generally over central Chester, Montgomery, or Bucks counties.

While the northeast-southwest orientation of high values of suspended particulates might be expected, the rather rapid decrease in concentration of suspended particulates to the east and west of this band of high concentration is more surprising. Wind rose data show the high frequency of westerly winds. Under conditions of winds from the northwest quadrant which must occur on the order of 30 percent of the time one would expect the band of high pollution to be spread eastward across parts of Gloucester, Camden and Burlington counties. Even with winds from the southwest quadrant, which are equally as common as northwest winds, the Philadelphia, Marcus Hook, Chester, and Wilmington sources of contamination might be expected to move northeastward over parts of Camden and Burlington counties. The fact that Pemberton in Burlington county has a relatively low value of suspended particulates (about the same as Embreeville and Pipersville well to the west of the urban-industrial pollution sources of the river valley) would lead one to infer that the areal movement or spread of suspended particulates is quite limited and that these pollutants are removed from the air fairly rapidly as the air moves from the source to the receiving area.

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, 1965

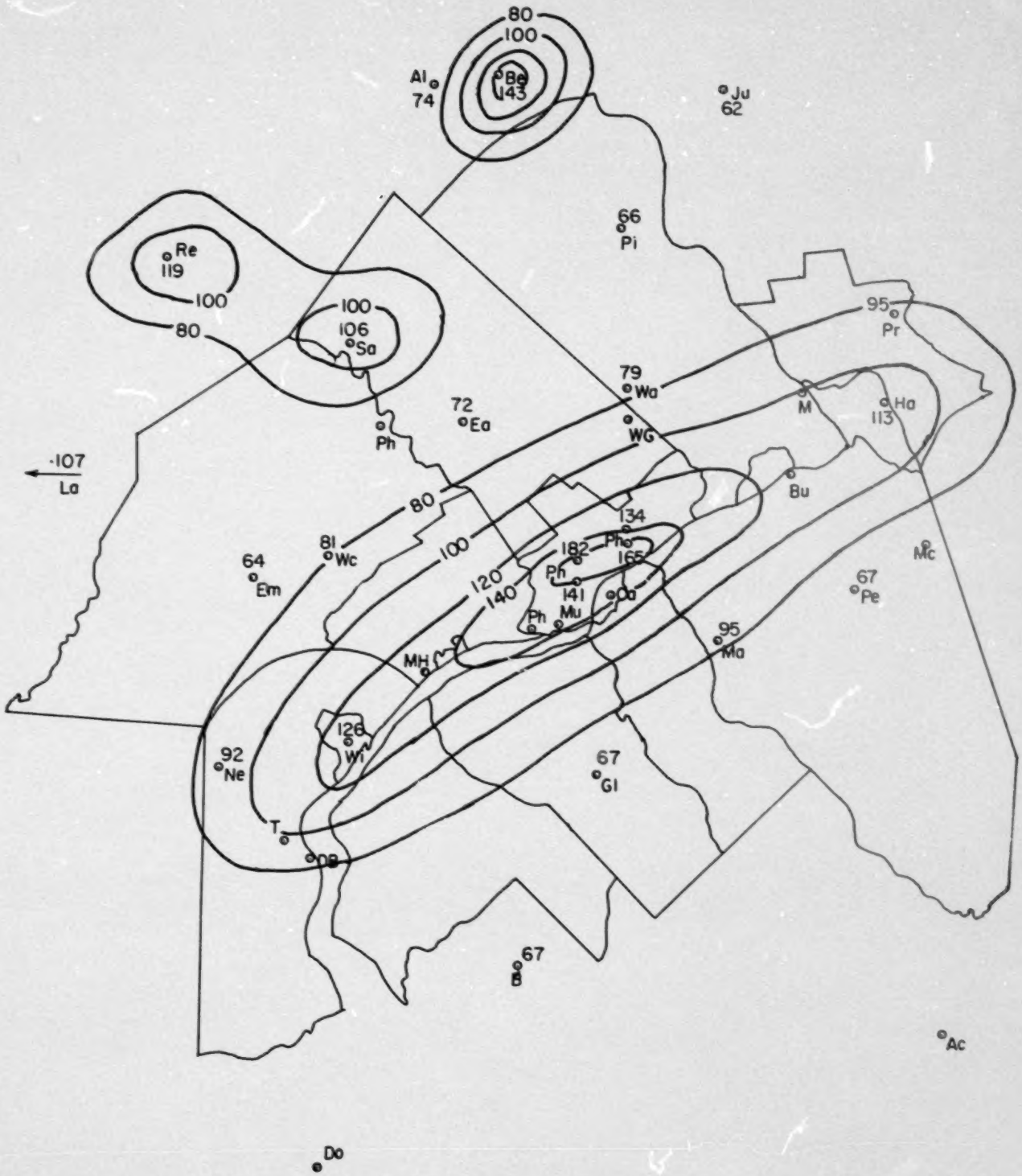

Figure 3

Conclusions

The present study of meteorology and air pollution in the Delaware Valley has involved an investigation of a) the availability of data and the existing and needed observation network; b) the air flow over the basin area; c) the stability conditions (inversions and mean mixing depths) that would influence the rate of mixing of the air with elevation; d) the varying air quality over the basin as it is related to synoptic meteorologic conditions; e) the possibility of using meteorologic conditions to forecast limiting pollution episodes; and f) detailed interpretation of several specific high pollution events.

A great many conclusions are possible based on the study to date. It is quite clear that a one year study does not provide sufficient time for study of all aspects of the problem but the preliminary conclusions seem fully justified on the basis of the available information.

A) Meteorologic data and observation network.

1. Reliable wind observation stations are not well distributed over the 11-county area. A large number are in the immediate Philadelphia area, but there are only a few in the western, northwestern, and southeastern part of the area. Additional wind recording stations in Chester, Bucks, Salem, Gloucester, and Camden counties would be very helpful in meteorological analyses.

2. A number of wind observing stations provide records of only limited usefulness because of problems of exposure, calibration, or reliability of the sensors and recording systems. Great care must be taken in evaluating all records of wind in an effort to recognize probable errors and to eliminate them.

3. Stations recording meteorological data should be set up and operated by individuals who have had some meteorological background or training in order to provide the most reliable and useful results. If this is not possible it might be preferable to forego the observing program rather than to collect incorrect observations.

4. Two stations recording the vertical profile of wind and temperature (only one above 300 ft) are not sufficient to provide a good understanding of the vertical distribution of these important meteorological factors over the area. The excellent vertical profile of temperature from the WFIL-KYW tower is influenced by its city location and one or two additional tower stations would be most desirable to provide a more complete meteorological analysis.

5. Stations measuring suspended particulates are well distributed but the relatively few observations per year limit the usefulness of the data. On certain selected days, similar observations should be taken at all stations in the area to allow the synoptic pattern of air quality to be determined.

6. Other factors of air quality in addition to suspended particulates must be measured on a fairly routine basis at more places in the area. While additional CAMP (Continuous Air Monitoring Program) stations would be desirable, it might not be necessary to have such a complete observing program at other stations. Two or three additional stations giving daily values of sulfur dioxide, nitric oxide, carbon monoxide and suspended particulates would be most helpful in any further air pollution analysis.

7. Vertical profiles of air quality would be desirable to have. The few available observations from the WFIL-KYW tower and from other study areas indicate a significant change in air quality with height. These changes would be better documented with a year or more of daily data.

B) Air flow over the basin.

1. The concept of an airshed or air basin has no real significance in the Delaware Valley area. The eastern seaboard from the coast westward to the Appalachian-Allegheny ridges and running north-south from at least Virginia to Massachusetts has to be considered as one continuous atmospheric area. Restricted river valleys or other isolated basins in the area are not airsheds and result in only localized eddies in the general air flow.

2. No portion of the basin area seems more prone to lowered air quality than any other on the basis of meteorologic and topographic conditions although the distribution of pollution sources does result in certain localized regions of higher pollution.

3. Late summer and early fall is the most favored time for long consecutive periods of light winds, of importance in increasing pollution hazard.

4. Prevailing winds over the basin are north of west in the winter season and south of west in the summer season. Wind velocities are higher in the winter than in the summer.

5. Wind roses prepared for periods of high and low air pollution reveal marked differences.

    a) Low pollution conditions are associated with strong winds predominantly from the northwest while high pollution conditions are much more frequently associated with low wind speeds or calms and southwest winds.

6. Wind roses during times of temperature inversions revealed no significant differences from wind roses prepared from all available wind data. Circulation conditions at times of inversions are not unlike circulation conditions at other times.

C) Stability of the air.

1. Inversions of air temperature are found in all seasons of the year with the peak number in the summer months (June-September). The summer period is also the favored time for more persistent inversions to occur (inversions lasting for several days).

2. Maximum mixing depths are lowest, and low mixing depths are most persistent in December and January although the greatest frequency of reasonably low maximum mixing depth (without regard for duration of the event) is in the summer and fall period.

3. The occurrence of low afternoon mixing depths, which reach a maximum in December, January, and February, seem to be related to air quality. When low values of mixing depth occur in the afternoon there is a good possibility that they will also occur in the early morning as well. Thus, low afternoon mixing depths reflect the possibility of stable conditions existing for 24 or more hours.

D) Air quality.

1. Peak values of different air pollutants do not occur at the same time suggesting that different environmental and meteorological conditions are responsible for their concentration in a particular area.

2. There is an above average level of pollution over the Delaware Valley area as a result of the heavy concentration of people and industry although only Philadelphia, Bethlehem, and Wilmington have suspended particulate concentrations above the national average for urban areas.

3. Soiling index, suspended particulate concentration, carbon monoxide, nitric oxide, and sulfur dioxide all experience higher values in the fall and winter periods of the year and lower values in the summer months. Nitrogen dioxide, total hydrocarbons, and total oxidants appear to experience higher values in the spring and summer months and lower values in the fall and winter season based on 1965 data.

4. Highest values of pollution in the valley area are found in Philadelphia with a fairly narrow band of high values of suspended particulate concentration running northeast-southwest along the highly industrialized river valley from Wilmington to Trenton. This band does not extend to any great degree to the northwest or southeast indicating relatively limited movement of suspended particulates downwind.

5. Day-to day variations in suspended particulate concentrations are much greater in winter than in summer although appreciable

variations occur in all seasons of the year. Periods with 2 or more consecutive days with values of suspended particulates well above or below the 20-day moving mean are fairly evenly distributed through the year with a few more periods in winter than in summer.

6. Daily values of suspended particulate concentration in Philadelphia are highest on Thursday and lowest on Sunday reflecting the weekly industrial and automobile activity. In suburban and rural areas, the weekly variation is much less noticeable with five different days having essentially the same values. A strong weekly bias would not be expected since these areas would not experience any strong weekly variation in industrial and automobile activity.

E) Forecasting pollution events from meteorological conditions.

1. Detailed study of periods of much above and below normal pollution reveals:

   a) The majority of the low pollution periods are associated with northwest winds and a polar continental air mass moving over the area from Canada. Most often the low pollution episode is initiated by the passage of a cold front with a deep low pressure center north of the area. The high pressure that pushes in behind the front brings cold, clear, northwest winds. Low pollution levels remains as long as the northwesterly flow continues.

   b) High pollution levels are not as clearly related to particular circulation patterns. With high pollution, the area is covered by a weak high pressure area, with light winds and little or no precipitation. The high pressure area remains stagnant over the area for several days or moves slowly to the southeast. Winds are generally from the southwest on the back side of the high pressure area.

2. Many different synoptic meteorologic situations exist during which increased air pollution occurs over the Delaware Valley. There are enough differences in these situations or there are enough times when similar meteorologic situations are found without high pollution to make it extremely difficult to forecast periods of high atmospheric pollution from the weather conditions alone.

3. The importance of non-meteorologic as well as meteorologic factors in air pollution makes it extremely difficult to forecast air quality from meteorologic factors by themselves.

F) Detailed case studies of high pollution episodes.

1. Even during extended periods of high atmospheric pollution (November 21-26, 1966, January 23-27, 1967) it is not necessary for inversion conditions to exist near the ground at all times. Unstable atmospheric conditions were observed for short periods in the middle of each day of the high pollution periods.

2. The top of the inversion layer is around 350 ft in Philadelphia although the lapse rate above is nearly isothermal up to the top of the tower observations (890 ft).

3. Most obvious characteristic of the wind field during a serious pollution episode is persistently low winds. Wind speed at 40 ft practically never exceeded 4 knots.

4. Highest air pollution levels are not strongly correlated with greatest inversions, nor are they consistently related to periods of lowest wind speeds. Peak pollution values at ground level are measured within a few hours after sunrise and may be largely a result of the fumigation process (downward transport during period of inversion breakup from below).

    a) Highest concentrations of sulfur dioxide were found aloft but below 500 ft (possibly near 350 ft). By inference, sulfur dioxide concentrations aloft over downtown Philadelphia may reach levels well above 1 ppm during a severe air pollution episode.

5. Two hundred foot towers are not sufficiently high to record some air pollution and meteorological data of significance for analysis.

G) General conclusions.

1. More important than the occurrence of any particular meteorological event is the duration of the limiting meteorological condition coupled with the non-meteorologic conditions of availability of pollutants. While the duration of limiting meteorological events may appear to be more favorable for pollution episodes in late summer and fall, it is only in the winter that meteorologic conditions combine with the abundance of pollution material to produce the most serious episodes of atmospheric pollution in this area. Thus any study of air pollution must be concerned with the seasonal occurrence of both meteorological conditions and atmospheric pollutants since serious pollution episodes result from the juxtaposition of both limiting factors.

2. The general pattern of air quality in the Delaware Valley is one of serious but not extreme conditions in any of the pollutants. The potential for very serious pollution exists and it is only because of the relatively favorable meteorological conditions that more serious pollution episodes do not develop.